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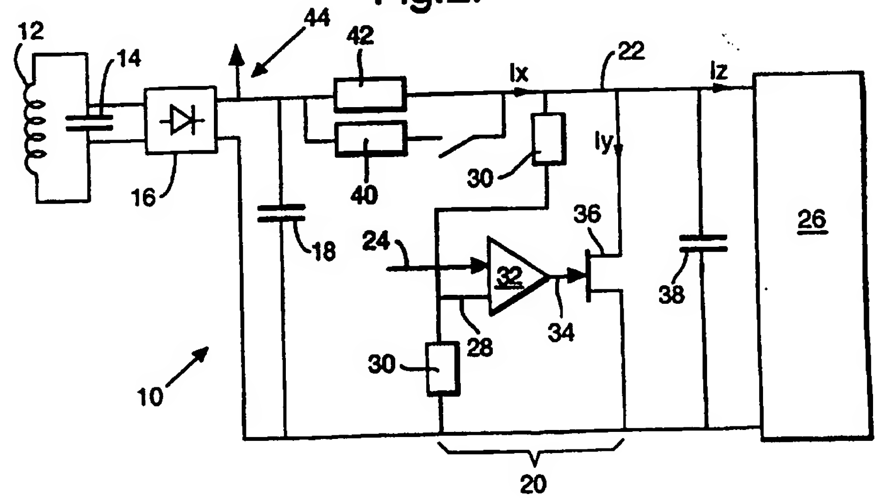
(54) Abstract Title
A contactless smart card having an inductive power supply with load resisistor

(57) A non-contact smart card 10 receiving power from a terminal by inductive coupling via an aerial 12 which is rectified by a rectifier 16 to provide a DC supply 22 and then regulated with a shunt regulator 20 includes a load resistor 42 (eg 500 ohms) to drop excess voltage provided by the rectifier in order to optimise the range of operating distance between the terminal and the card. An extra impedance 40 (eg 3k ohms) can be switched in parallel to resistor 42.

Fig.2.



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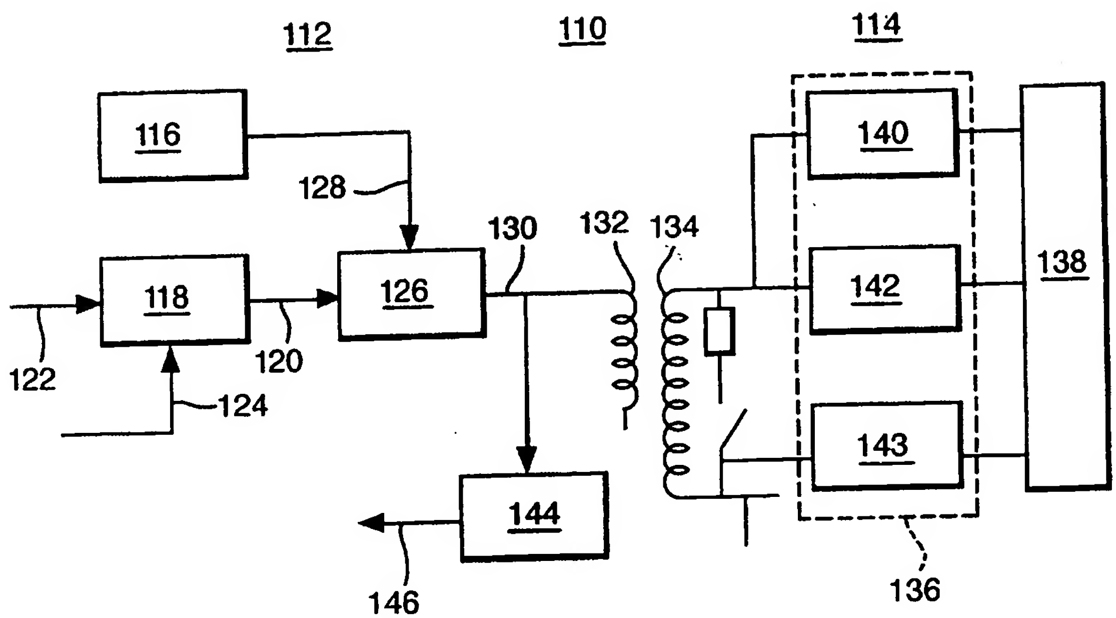
At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

Fig.1.


112
110
114
116
128
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132
134
118
126
140
142
143
138
122
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124
144
146
136

Fig.2.

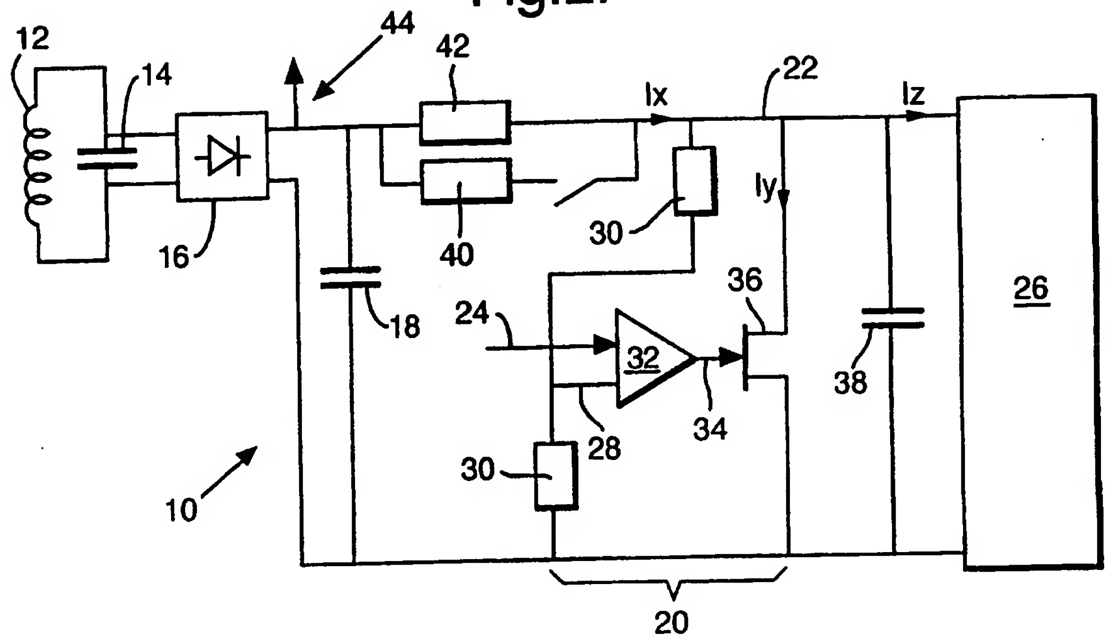
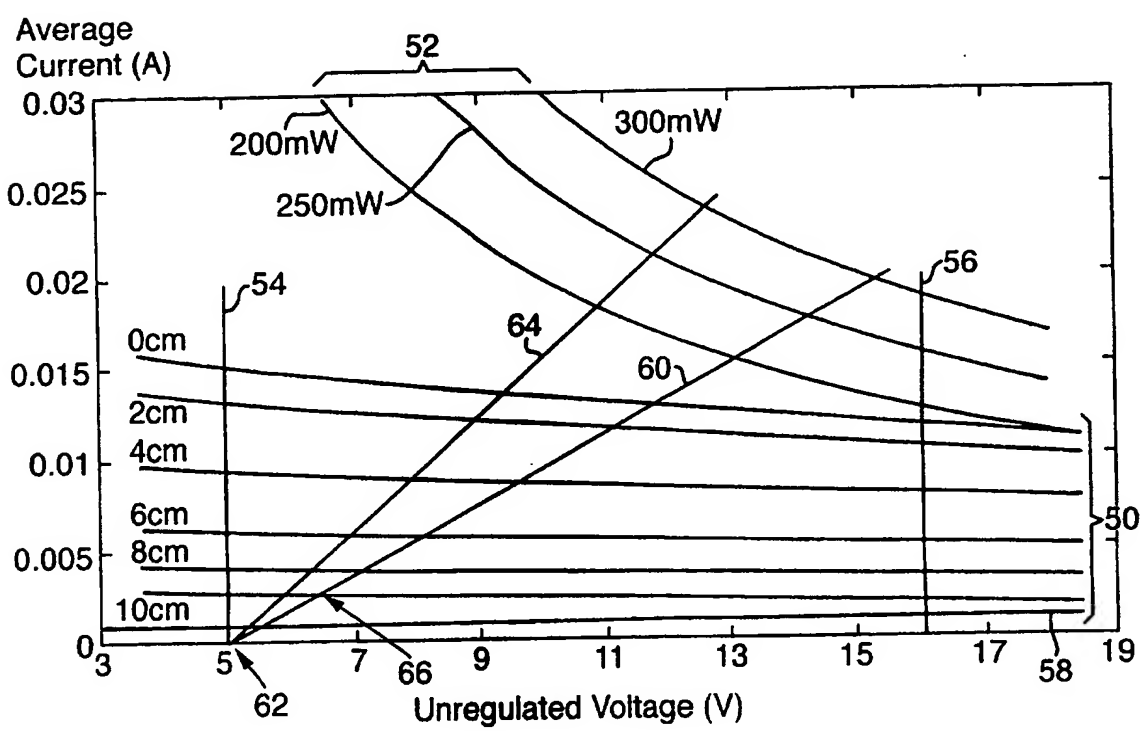

12
14
16
44
42
40
Ix
22
Iz
Iy
30
26
18
24
32
36
34
38
28
30
10
20

Fig.3.


Average Current (A)
52
0.03
0.025
0.02
0.015
0.01
0.005
0
200mW
250mW
300mW
54
56
64
60
0cm
2cm
4cm
6cm
8cm
10cm
50
3
5
7
9
11
13
15
17
19
62
66
58
Unregulated Voltage (V)

2333495

TRANSACTION SYSTEM

This invention relates to a transaction system in which a portable token, for example a card, is used in conjunction with a device, often termed a terminal, to perform a transaction of some kind. The invention is particularly, but not exclusively, related to contactless smart cards.

Contactless tokens work on, or close to, a terminal which provides power. This power is supplied via a RF (radio frequency) induction field which is referred to as a carrier field. Power is transferred from an aerial in the terminal to an aerial on the token and is akin to the terminal being a primary coil of a transformer and the token being a secondary coil. In particular embodiments both the terminal and the token each have a single aerial each of which may comprise a coil having one or more turns.

As well as power being transmitted from the terminal to the token, data is transmitted from the terminal to the token and vice versa. The exchange of data is used to perform a transaction. To transmit data to the token the terminal modulates it onto the carrier field. To transmit data to the terminal, the token switches an impedance to modulate the amplitude of the carrier field at the terminal as the token draws extra power from the terminal aerial due to the switching action.

As technology improves the power consumption of tokens is being reduced. This means that tokens can work further away from their terminals, and so the volume or field of operation of terminals is becoming larger.

The amount of carrier field picked up by the aerial of the token varies with token orientation and position with respect to the terminal aerial. Typically the amount of carrier field picked up by the token can vary by a factor of ten from the token being adjacent to a 10cm terminal aerial to the token being 10cm away from the terminal aerial. As a result the token receives a variable AC voltage supply. Rectification of the AC voltage supply provides the token with an unregulated DC voltage supply which is also variable. Token controllers require a reasonably steady voltage supply to give reliable performance. For this reason a regulator is usually incorporated into circuitry connected to the token aerial in order to regulate the unregulated voltage supply.

In order to ensure reliable operation of the controller, voltages supplied to it must be within maximum and minimum values. For example, the voltage supply to a controller should not vary by more than 10%. Although variation of ±20% might be tolerated, the controller might become unreliable in operation. Typical operating voltages are 3V or 5V with a variation of ±10%. If less voltage than the minimum operating value is supplied the controller will not work reliably. If more voltage than the maximum operating value is supplied circuits in the controller could be damaged. The maximum value is limited by the characteristics of circuits on a controller silicon die and the technology used in their manufacture.

Two methods are known to ensure supply of a stable voltage supply to the controller. In the first method, voltage supplied to the controller is controlled with a shunt regulator set at, say, 5V. This means that at any particular separation of the terminal and the token

there is a certain current available. Excess current is taken by the shunt regulator to maintain or control the voltage supplied to the controller. Use of a shunt regulator allows a contactless token to work over a large range of distances from the terminal without the controller receiving too much power. In the second method, the token is provided with a constant current source and a series regulator to ensure that there is sufficient current for the controller and also to ensure that its voltage supply is maintained. If a constant current is taken by the controller, voltage varies with separation and the series regulator absorbs excess voltage.

Problems exist with both methods. In the first method, the token sends data to the terminal by altering the effect of its load on the carrier field of the terminal. Conveniently this is achieved by changing the impedance of the token in the carrier field as perceived by the terminal. Since the shunt regulator compensates for any changes in load, changes in current drawn by the controller due to different instructions or changes in clock speed are compensated for by the shunt regulator and so do not perturb the carrier field and thus do not appear as data from the token.

An undesirable side-effect of the shunt regulator is that it also compensates for deliberate load changes which are being caused by the token to send data to the terminal. This particularly applies if amplitude modulation is being used as the transmission method. However, amplitude modulation is preferred because it is a simple and straightforward method to implement. The shunt regulator also affects data being sent to the token if amplitude modulation of the carrier field is being used. Variations of

voltage on the token which are induced by modulation of the carrier field are suppressed by the shunt regulator thus inhibiting reception of data from the terminal.

Considering now the second method, although a series regulator does not inhibit signals to and from the token in an equivalent way (since it does not fix the input voltage), it has other disadvantages. If the current source which supplies current to the series regulator is arranged to supply a relatively large constant current of, say, 10mA, then the token only works close to the terminal. If a relatively small current is supplied, say 1mA, then the token will operate at larger separations from the terminal because it consumes less power (and the power available from carrier field decreases with increasing token separation from the terminal). As only a small current is available from the current source only a small current can be supplied to the controller. Furthermore, if placed very close to the terminal there is a risk that the breakdown voltage of the controller will be exceeded because the voltage will rise to compensate for the small current being taken. In addition, a series regulator has a voltage dropout and so its use will restrict the input voltage range available to the controller.

According to a first aspect the invention provides a contactless token for communicating with a terminal of a transaction system the token and the terminal communicating via an inductive coupling the token having a rectifier for providing a DC power supply and a regulator for regulating the DC power supply characterised in that the token is provided with a load impedance located between the rectifier and the regulator which drops excess voltage across itself at high voltages in order to increase the range of

operating distance between the token and the terminal.

Preferably the terminal generates a carrier field. Preferably the excess voltage is highest when a large carrier field is present and lowest when a small carrier field is present.

Preferably the regulator is a shunt regulator.

Preferably the load impedance is a resistor. Alternatively it could be an active load whose resistance is set, and possibly altered, by a control circuit. Advantageously its resistance value may be set so that the breakdown voltage of the controller is not exceeded when the token is close to the terminal.

Preferably the load impedance can be modified by switching in an extra component, circuit or sub-circuit so as to cause modulation of the carrier field at the terminal aerial. The extra component, circuit or sub-circuit may be an impedance. Preferably the extra component, circuit or sub-circuit is switched in in parallel. Alternatively, it may be switched in in series. Preferably if the load impedance is an active load its value can be set, and possibly altered, by a control circuit.

Preferably the token transmits data to the terminal by altering its own impedance in the carrier field. This may be detected by the terminal as data represented by amplitude modulation.

Preferably the load impedance drops less voltage across itself at low voltages.

Preferably low voltages are in the range 3 to 6V. Most preferably a low voltage is substantially 3 or 5V. Preferably high voltages are in the range 15 to 21V. Most preferably a high voltage is 18V.

According to a second aspect the invention provides a transaction system comprising a token in accordance with the first aspect of the invention and a terminal.

An embodiment of the invention will now be described by way of example only with reference to the accompanying drawings in which:

Figure 1 shows a schematic representation of a transaction system;

Figure 2 shows a schematic representation of the electrical circuitry of a contactless token; and

Figure 3 shows voltage and current characteristics of a token at a number of different separations from a terminal.

Figure 1 shows a transaction system 110 comprising a terminal 112 and a token, such as a smart card, 114. The terminal 112 has a carrier source 116 and a modulation source 118. The modulation source 118 produces a modulation signal 120 which is a data signal. The modulation signal 120 may contain raw data 122 such as transaction related information and instructions. It may also contain a clock signal 124. The clock signal may be present as a tone which is modulated by the raw data 122. A carrier modulator

126 uses the modulation signal 120 to modulate a carrier source signal 128 produced by the carrier source 116. As a result the carrier modulator 126 produces a modulated carrier signal 130 which is transmitted by an aerial 132 to be received by the token 114.

The token 114 has an aerial 134 and an interface 136 which is connected to a controller 138 such as a microprocessor. The aerial 134 receives the modulated carrier signal 130 and from it the interface 136, and thus the controller 138, extracts a clock and a data signal 140 and power 142. The controller 138 processes the data signal 140 to produce its own data to be transmitted to the terminal 112 to conduct a transaction.

Transmission of data from the token to the terminal is carried out by switching an impedance 143 across the aerial 134 and thus changing the amount of power drawn by the token 114 from the carrier signal of the terminal 112. The terminal 112 receives a signal representative of the impedance switching and detects the token data in data receiving means or a detector 144. Extracted data 146 is then processed by the terminal 112.

Figure 2 shows a token 10 in a schematic representation and, more particularly, shows its power supply circuit for its electronic controller or processor. The token 10 has an aerial 12 which is tuned by a capacitor 14. This makes power extraction more efficient at large separations of the token and a terminal (for example 10cm) because it amplifies induced voltage. AC power induced in the aerial 12 and capacitor 14 is converted to DC power by a rectifier 16. In the present embodiment this is a full bridge rectifier. The

output of the rectifier 16 is smoothed by a capacitor 18 to reduce voltage ripple. The rectifier 16 produces an unregulated voltage supply 44 which is connected to a shunt regulator 20 via a load resistor 42. The shunt regulator 20 regulates voltage supply 22 which is supplied to a controller 26, such as a microprocessor. The shunt regulator 20 operates by comparing the controller voltage supply 22 to a reference voltage 24. In one embodiment the controller voltage supply 22 is scaled to a voltage 28 typically in the region of 1.25V by a resistor chain 30. The voltage 28 is compared to the reference voltage 24 which is also typically in the region of 1.25V. The reference voltage is supplied by a bandgap circuit. In an alternative embodiment the token may use a Zener diode structure to protect the controller 26 from over voltage.

The difference between voltages 24 and 28 is amplified by an operational amplifier 32 to provide a control signal 34 which controls operation of a transistor 36, which is typically a FET. The transistor 36 takes a proportion of current (I_y) from the current supplied by the rectifier (I_x) to stabilise and fix the controller voltage supply 22. Residual current I_z is supplied to the controller 26. The controller voltage supply 22 is used by the controller 26 for its power needs which can vary depending on the operation it is carrying out, for example writing to memory. Capacitor 38 is used to decouple the power supply of the controller. It supplies the current for any current spikes required by the controller which the regulator is not fast enough to provide and so helps provide a stable voltage supply for the controller 26. Current spikes normally occur on clock edges due to the way the controller logic works, which is usually synchronous logic.

The power drawn by the token 10 from the carrier field of a terminal depends on various factors including coupling factor k, the impedances of the terminal and the token and the current flowing in the terminal aerial. However, to enable the token to send data to the terminal it is provided with an extra impedance 40, typically having a resistance of 3kΩ which can be switched in parallel with the load resistor 42 so as to alter its value. This causes the impedance of the token to change, which can be perceived by the terminal as a small voltage change in its aerial. In tokens according to the prior art, the unregulated voltage supply provided by the rectifier changes as the impedance in the token is switched for the token to transmit data, but the shunt regulator stops the impedance change affecting the controller voltage supply 22 of the controller 26 and inhibits data transmission from the token. In tokens according to the invention, the unregulated voltage supply 44 also changes when data is transmitted by the token but this does not affect the controller voltage supply 22 because excess voltage is dropped across impedance 40 or the combination of load resistor 42 and impedance 40.

Although it is preferred that the impedance 40 and the load resistor 42 are the same type of component, for example both impedances and preferably both resistors, they can be different. Component 40 does not have to be an impedance, but could be a weak current sink or a voltage clamp. The only requirement of component 40 is that it is able to alter the impedance of the token in the carrier field of the terminal.

The load resistor typically has a resistance of 500Ω. The effect of the load resistor is best explained with reference to Figure 3.

Figure 3 is a graph showing unregulated voltage supply in the token against current drawn by the token. As is explained above in relation to Figure 2, the unregulated voltage supply and current are DC supplies provided by the rectifier 16.

A number of characteristic lines 50 are shown each indicating current (I_x) against unregulated voltage provided by the rectifier 16. Each line represents a specific separation between the aerials of the token and the terminal. The distances are 0 to 10cm at 2cm intervals. The characteristic lines 50 have a negative gradient because the DC power supplied by the rectifier 16 is equivalent to a supply provided by a voltage source which has a resistance. However, the combination of the terminal, the inductive coupling between the terminal and the token 10 and the rectifier 16 is only equivalent to a voltage source and a resistor and so the lines 50 are curved rather than straight. As less current is drawn, more voltage is available. As the token gets closer to the terminal it receives more current, more voltage and therefore more power. The characteristic lines 50 can be determined empirically or by analytical methods. As can be seen in this case, they are fairly horizontal so the terminal inductive coupling and the token rectifier are acting like a current source.

Obviously the current and voltage received by the token depend on the efficiency of the inductive coupling between the token and the terminal, that is on a coupling factor k having a value between 0 and 1. In Figure 3 it is assumed that the coupling factor is a constant value for each separation.

Also shown on the graph are a number of power lines 52 each of which shows how values of voltage and current vary in providing a fixed value of power to the token. The lines 52 show the variation with received power values of 200, 250 and 300mW. The controller, or more particularly the silicon die in the controller, can only dissipate a certain amount of power. If the controller receives more power than this, it may overheat and become damaged. A typical maximum power for a controller is 250mW. However, since this value varies with ambient temperature a slightly lower value is preferred. As the ambient temperature increases, the less maximum power the controller will be able to withstand because there is a maximum die operating temperature beyond which the die will be damaged.

The power lines 52 define upper operating characteristics for the token. For example a silicon die capable of working up to +125°C in an ambient temperature of 75°C which is packaged in token material providing heat sinking of 250°C/W, will be able to dissipate up to 200mW without damage. Assuming that a controller can withstand a maximum power of 200mW, this shows that at a separation of 0cm its unregulated voltage should not exceed 18V. Alternatively, it can be seen that even at zero separation a token will not exceed its maximum power across a full voltage range, that is up to 18V.

It should also be noted that the maximum power dissipation (effectively the relative amounts of voltage and current) is not always at 0cm separation between the token and the terminal. In some cases this may be at greater separations, for example 1.5cm. This

is because the maximum power dissipation in the token occurs at a critical coupling point which depends on the Q-factors of the aerials of the token and the terminal. If the critical coupling point is exceeded beyond a separation of 0cm power dissipation will fall as the token becomes closer to the terminal than the critical coupling point.

Minimum and maximum voltage limits, 54 and 56 respectively, define the operating range of the token. Minimum voltage limit 54 is set by the shunt regulator 20 which clamps the controller voltage supply 22 to 5V. Limit 56 shows a typical breakdown voltage limit of 16V. There are higher voltages on the front end of the rectifier due to rectifier dropout. Limit 58 shows a typical minimum current, say 1mA, required by a controller to operate. This current will be determined by the clock speed of the token and the operations which it is performing.

Line 60 is the load characteristic imposed by having the load resistor 42 inserted between the rectifier 16 and the regulator 20. One end of the line 60 is point 62 which is set by the shunt regulator 20 clamping the controller voltage supply 22 to 5V. If the voltage supply was not clamped below this point the controller 26 would have an unstable power supply. The gradient of line 60 is determined by the resistance of the load resistor 42. If the impedance 40 is switched in parallel with the load resistor 42, the combined resistance of resistors 40 and 42 in parallel is lower than the resistance of the load resistor 42 and so load characteristics of the token change from line 60 to line 64. It should be noted that line 64 also originates from point 62.

By changing the resistance value of the load resistor 42 to that of the load resistor 42 and impedance 40 combination, the characteristic of the load resistor 42 changes from that of load line 60 to that of load line 64. Therefore, the overall load of the token changes which affects the voltage in the aerial in the terminal. The change may be detected by the terminal as amplitude modulation. More importantly this switching in of impedance 40 does not affect the performance of the shunt regulator 20 at any separation. Therefore the voltage supply to the controller remains stable. The change in loading due to data transmission compensates with separation, for example it is weaker at larger separations where there is less available power to use. When transmitting from the terminal to the token it had been stated previously that amplitude modulation (AM) would be preferred. The load resistor 42 allows AM to be received without affecting the operation of the shunt regulator 20. Furthermore, it allows the rectifier to be used to AM demodulate the carrier as well as provide power supply to the token. The signal at 44 is removed from the influence of the clamping of the shunt regulator 20, therefore the signal AM modulated on the carrier now appears on the DC power supply at 44 with the carrier ripple reduced by the capacitor 18. Data can be extracted by a detector AC coupled to 44. This signal could be data or a tone for use in providing a controller clock or both.

The resistance of the load resistor is chosen so that both the unregulated voltage limit 56 and the maximum power dissipation are not exceeded at the critical coupling point. Usually this is at a small separation, for example 0cm. The load resistor 42 dissipates excess power across itself. The closer the token is to the terminal, the more voltage it

drops across itself. The shunt regulator 20 does not drop any voltage.

At large separations, for example 10cm, the presence of the load resistor 42 means that the operating point is defined by line 60 and is at point 66. The token still works and provides more than the minimum necessary current for the controller. This is because less voltage is dropped across the load resistor 42. Therefore, the presence of the load resistor 42 maximises the separation at which the token and the terminal can operate.

The load resistor 42 fixes the maximum current available at any separation so if a token is separated from the terminal by a relatively large distance there is a minimum current available which will enable a controller at least to do certain operations at slow clock speeds. As the token is brought closer the load resistor 42 allows more current to become available allowing the controller to do more complex operations or operate at higher clock speeds. Therefore the token may take, for example, 1mA at 10cm which allows it to work at 10cm and may also take 15mA at 0cm. Therefore this allows it to make maximum use of current available to it, and so the token is not restricted to operation at small separations. Clearly this provides an advantage over a token with a low constant current supply.

The controller 26 can take any value up to the maximum permitted by the load resistor 42 at a particular separation because the shunt regulator 20 takes any excess. Therefore variations in I_z (controller current) are compensated by shunt current I_y since $I_y + I_z = I_x$ (where I_x is the maximum permitted current via the load resistor 42). Therefore

controller load variations are not transmitted to the terminal and therefore are not detected as data transmissions from the token. I_x remains constant if the separation is constant although it does change with changing separation.

CLAIMS

1. A contactless token for communicating with a terminal of a transaction system the token and the terminal communicating via an inductive coupling the token having a rectifier for providing a DC power supply and a regulator for regulating the DC power supply characterised in that the token is provided with a load impedance located between the rectifier and the regulator which drops excess voltage across itself at high voltages in order to increase the range of operating distance between the token and the terminal.

2. A token according to claim 1 which is powered by a carrier field generated by the terminal.

3. A token according to claim 2 characterised in that the load impedance is modified by switching in an extra component, circuit or sub-circuit so as to cause modulation of the carrier field at the terminal aerial.

4. A token according to claim 3 characterised in that the switching of the extra component, circuit or sub-circuit is detected by the terminal as data represented by amplitude modulation.

5. A token according to any preceding claim characterised in that the load impedance is a resistor.

6. A token according any preceding claim characterised in that the load impedance has a resistance value which is set so that the breakdown voltage of the controller is not exceeded when the token is close to the terminal.

7. A token according to any preceding claim characterised in that the regulator is a shunt regulator.

8. A token according to any preceding claim characterised in that the load impedance drops less voltage across itself at low voltages than it drops across itself at high voltages.

9. A token according to claim 8 characterised in that the load impedance drops excess voltage across itself at high voltages.

10. A token according to claim 8 or claim 9 characterised in that low voltages are in the range 3 to 6V.

11. A token according to claim 8 or claim 9 characterised in that a low voltage is substantially 3 or 5V

12. A token according to any of claims 8 to 11 characterised in that high voltages are in the range 15 to 21V.

13. A token according to any of claims 8 to 11 characterised in that a high voltage is 18V.

14. A contactless token substantially as described herein with reference to the accompanying drawings.

15. A transaction system comprising a token in accordance with any preceding claim and a terminal.

16. A transaction system substantially as described herein with reference to the accompanying drawings.

The Patent Office

19

Application No:	GB 9803381.4	**Examiner:**	Graham Russell
Claims searched:	1-16	**Date of search:**	14 May 1998

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): B6A (AK)

Int Cl (Ed.6): G06K 19/07

Other:

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	WO 89/07295 A1	(MAGELLAN) see page 1 lines 14-18 and page 2 line 23 - page 3 line 37	1,5
X	US 4857913	(SOCIETE FONTAINE) see column 3 lines 52-64	1,5

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